Multi-Story Tilt-Up Buildings

A Design Approach

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Five-story tilt-up building. Courtesy of Tilt-Up Concrete Association, ©John Gillan Photography.

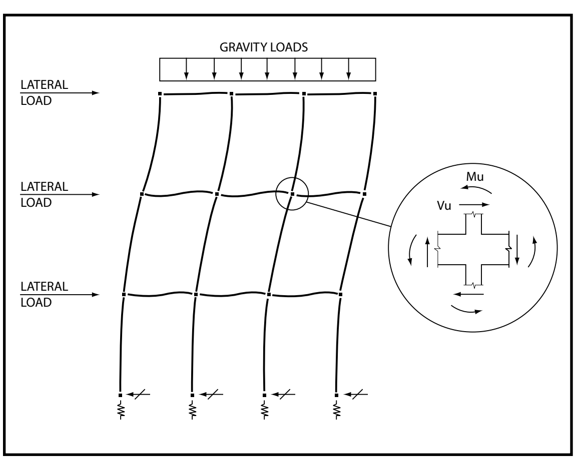
Tilt-up construction is continuing to grow at a record pace. Over the past three years, about one billion square feet of tilt-up wall panels have been constructed to provide approximately 2.3 billion square feet of usable floor space. While a significant percentage of this growth has come from single-story building construction, the multi-story tilt-up market has really begun to flourish. The design of these multi-story tilt-up buildings is significantly more involved than that of single story buildings.

EOR versus Specialty Engineer

While many multi-story tilt-up buildings are designed in whole by the engineer of record (EOR), quite often the design of the tilt-up panels is left up to a tilt-up specialty engineer. This delegation of duties need not be a stressful event for either professional, as long as each is aware of his or her specific responsibilities. The tilt-up specialty engineer's scope can be restricted to only panel thickness and reinforcing design, or can include many other items such as panel overturning stability analysis and design of panel-to-structure and panel-to-panel connections.

It is very important for the EOR to make it clear in the design documents what is expected from the tilt-up specialty engineer. Floor and roof loads to the wall panels should be listed on the framing plans, including both beam reactions and distributed loads, such as those along an endwall. These gravity loads should be broken down into dead and live load components so that an efficient design can be achieved for the concrete panels. The wind uplift loads should also be specified for the roof framing members.

It should be obvious from the design drawings whether the tilt-up panels are expected to resist in-plane lateral loads from the floor and roof diaphragms. Design values for both wind and seismic loads must be provided, if they are applicable. Each floor plan should indicate the loads to each individual wall that participates in resisting lateral loads. Note that these loads might vary from floor to floor, especially in high seismic areas.



Computer model for in-plane load analysis.

In-Plane Loads and Lateral Stability

Many of the multi-story tilt-up structures currently being constructed are office buildings. These range from three to six stories, are typically rectangular in plan, and have tilt-up panels that are full of punched openings for windows. On a rectangular office building, the endwalls may not have enough capacity or overturning stability to resist the lateral loads. In this case, interior bracing or shearwalls must be provided to resist the lateral loads in the short direction of the building. The stiffness of the bracing or shearwalls should be compared to the stiffness of the endwalls to ensure that the latter do not actually end up resisting the lateral loads.

The design of panels with many openings is much more complicated than the design of simple solid panels. While the in-plane shear is usually provided as a load per foot of wall length, the distribution of this load among adjacent panels is typically not uniform. The lateral loads are distributed to the wall panels based on the relative stiffness of the concrete column sections between panel openings. This method of load distribution applies not only between panels, but also between strips within a panel. For multi-story buildings with many panels and openings, it is most efficient to model each wall as a series of concrete frames, including both column strips between openings and beams strips above and below openings for each panel. The panels are linked together at each floor level in the model so that the lateral loads are distributed across them. Vertical loads are also included in this analysis, providing a complete picture of the axial loads, shears and bending moments in the column strips and beam strips.

It is not unusual to find that the resultant of the vertical loads will be shifted towards one side of the panel due to the overturning effect of the lateral loads. Because of the frame action of the panel, the beam strips above and below the openings can be subject to relatively large shears and moments that must be accounted for in the design of the panel reinforcing. Design of the column strips should account for the axial loads, the in-plane moments from the frame analysis, and the out-of-plane moments caused by wind or seismic effects.

Load-Bearing versus Non-Load-Bearing Panels

Multi-story tilt-up building wall panels can be either load-bearing or non-load-bearing for the interior framing members. For non-load-bearing panels, perimeter columns and edge beams are provided to support the vertical floor and roof loads. Load-bearing panels eliminate the need for this perimeter framing, which in most cases leads to a more economical design. In addition, the use of non-load-bearing panels as shear walls is somewhat difficult, since the connection between the panel and the structure must accommodate the vertical deflection of the perimeter framing. In fact, it is desirable to use load-bearing panels as shear walls because the added vertical loads increase the overturning resistance.

Second tier tilt-up panel lifted into place.

Some recent multi-story office buildings have used a combination of load-bearing panels and perimeter framing. The typical floor beams at the sidewalls and the deck at the endwalls are supported by the panels, while the girder reactions are supported on perimeter columns. This arrangement actually works quite well when the girder reactions are large and would otherwise require a heavily reinforced concrete wall section or pilaster.

The increased vertical forces on load-bearing panels can have an effect on the panel thickness, leg width between openings, and panel reinforcing. However, this effect is not usually significant, because for multi-story panels, construction loading and lifting configuration also affect the design. In many cases, the construction loads are actually more critical for the design of the panel thickness and reinforcing than the final, in-place design loads, although obviously both should be accounted for in the design.

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Structural Integrity – Full-Height versus Stacked Panels

Tilt-up buildings up to three stories tall are generally constructed using full-height panels. For taller buildings with more floors, it may be more economical to construct the wall using a stacked panel arrangement. A stacked panel configuration is constructed by locating a horizontal panel joint a few feet above one of the supported floors, typically at a reveal location so that the joint can be hidden. The height of the individual panels in the stack can vary depending on design and construction issues. The bottom building panels are erected first, followed by construction of the supported floors up to the top level of that panel. The second tier of panels is then erected on top of the lower panels and braced down to the already constructed floor. The selection of panel heights and sequencing of the stacked panels should involve the general contractor that will be performing the construction.

Grout sleeve connection between stacked panels.

A variety of factors can influence the decision to use a stacked panel arrangement. These include available panel casting area, crane size, lifting hardware capacity, panel thickness, panel bracing configuration and construction sequence and timing.

ACI 318 has structural integrity provisions that must be incorporated into the design of multi-story tilt-up buildings. These requirements address longitudinal and transverse tie requirements for supported slabs, as well as vertical tension tie requirements for the wall panels, including stacked panel configurations. For bearing wall structures three or more stories in height, there are specific load and spacing requirements for the structural integrity connections.

The connections between stacked panels are designed to transfer all design loads across the joint. These include in-plane shear from diaphragm loads, out-of-plane wind and seismic forces, tension forces due to panel overturning, and in-plane moments across the horizontal joint. The structural integrity requirements are not additive to these design loads. Connections that rely solely on friction to transfer loads are not allowed. For stacked panels, a minimum of two connections between panels capable of providing a nominal tensile strength of 3000 pounds per horizontal foot of wall are required. Each connection must have a nominal tensile strength of 10,000 pounds. These connections are typically placed at a maximum spacing of four feet on center, with some concentration at each end of the panel. One commonly used type of connection that meets the above design requirements uses reinforcing bars extending from the lower panel that are inserted into a grout sleeve in the upper panel.

Erection Bracing Options

There are three basic options for bracing multi-story panels. The simplest and most common configuration is bracing to the slab on grade on the inside of the building. The slab must be checked to ensure that it can resist the brace forces. This includes verifying that it meets not only the stability requirements for the uplift and sliding forces from the brace reaction, but also that the slab has the strength (i.e., thickness and reinforcing) to resist these loads. Panels can also be braced to the outside of the building using a cast-in-place deadman or helical ground anchors. The use of the helical ground anchors has only recently been applied to tilt-up construction. They have the advantage of fast installation and removal, as well as a verifiable capacity. The anchors are field tested to ensure that they meet the load requirements of the panel braces.

With stacked panels, bracing the upper panels to the building floor structure becomes a concern. The braces are attached to the supported floor below the horizontal panel joint between stacked panels. The supported floor slab capacity should be checked to verify that it has the strength to resist the brace forces. Similarly, the floor framing must have the strength to support the brace loads. For a precast concrete floor system, the bracing loads and locations should be provided to the precast supplier for incorporation into the design of those elements.

Connection Design at Floors and Roof

Connections of tilt-up panels to the main structure are required to resist gravity loads, wind (in- and out-of-plane), seismic (in- and out-of-plane), and thermal bowing. Non-load-bearing panel-to-structure connections must be designed to allow vertical deflection of the perimeter load-bearing steel or concrete framing. Slotted inserts are usually sufficient to achieve this, and are available from several manufacturers. In addition to the wind and seismic out-of-plane forces, the connections should also be designed to resist thermal bowing. The method of calculation for these forces can be found in the *PCI Design Handbook*.

For buildings constructed with load-bearing panels and cast-in-place floor slabs, joist or beams bearing on the sidewalls are usually connected to panels using framing angles or seated connections attached to embed plates cast into the panel face. The use of pocketed connections is not recommended, as it can interrupt the vertical reinforcing in the structural strips between openings. On building endwalls, the panels will be directly connected to the cast-in-place slab using rebar wall ties or a similar system. These ties will transfer diaphragm loads, out-of-plane wind/ seismic forces, and gravity loads. For concrete slabs over metal deck at endwalls, the gravity loads are supported on a continuous edge angle, which is supported by embed plates cast into the panel. Wall ties should also be used on the sidewalls to transfer lateral loads into the panels and out-of-plane loads from the panels into the floor system.

For buildings with precast concrete floor and roof systems, coordination between the precast supplier and the tilt-up panel engineer is required to determine the locations and types of connections that are needed. For gravity load support of the precast systems, a corbel is often incorporated into the wall panel design. This can be a continuous corbel for hollow-core planks or individual corbels for double tee stems. A positive connection to the panels is still required to transmit the in- and out-of-plane forces between the floor system and the wall panels while accommodating vertical deflection of the members at the endwalls.

Roof connections for steel-framed multi-story tilt-up buildings are very similar to those used for single-story structures. Lateral diaphragm loads on the sidewalls are transmitted to the wall panels through the framing member connections or directly into the wall panel through a continuous perimeter angle, which can be connected to the wall panel with bolts or embed plates. Out-of-plane loads are transferred directly into the roof framing members. At building endwalls, the perimeter angle connection to the wall panels transfers wind uplift and gravity loads, diaphragm shears, and out-of-plane loads between the tilt-up panel and roof structure. Panel-to-roof-structure connections for precast concrete roof systems are similar to those used for precast concrete floor systems.

Conclusions

While the design of multi-story tilt-up buildings shares many similarities to the design of single-story tilt-up buildings, there are a number of additional engineering issues to address. The design engineer must understand the load path and how the applied loads can affect the wall panel design, which may have portions affected by torsion, uniaxial bending, biaxial bending, tension and compression. In addition, a thorough understanding of the design tools (i.e. computer programs) used to engineer the tilt-up wall panels is equally important.

Building design and construction is a team effort. Cooperation and coordination between the design professionals (i.e., the EOR and tilt-up specialty engineer) is critical to the successful design of a tilt-up building. They share a common goal: the safe engineering design and construction of a building that meets the needs of its owner.▪

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